INSULATOR BEHAVIOR IN CONTAMINATED ATMOSPHERES

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INTRODUCTION

The conditions leading to flashover in contaminated atmospheres are very complex and do not always permit simple choices of insulator types for good performance. Increased understanding concerning performance under salt contamination has been realized, and reasonably good correlation between artificially contaminated insulators and pollution under natural environment is possible.

The authors wish to point out that pollution in industrial atmospheres is highly variable and needs much greater investigation and study.

It is generally accepted that contamination on the surface of an insulator results from the deposition of airborne particles. However further explanation of this process is needed to understand some of the difficulties involved in duplicating natural pollution with artificial pollution. At least two mechanisms can be involved, separately or simultaneously. The first is identified as mechanical contamination. Mechanical contamination is the manner in which salts are transferred to the insulator surface via wind borne aerosols or by aqueos contaminants deposited under moist conditions. Greater surface adhesion is expected under moist or damp conditions. Contamination by soluble salts particularly in coastal areas would be classed as mechanical deposition. A second mechanism is identified as chemical change. Contaminants formed by this method are not originally present but are chemical compounds formed by a chemical reaction initiated by airborne substances. For instance zinc sulfate has been found on insulator surfaces. This suggests that sulfur compounds (hydrogen sulfide, hydrogen sulfate, sulfur dioxide and sulfuric acid) under the influence of an oxidative agent (ozone) can react with galvanized surfaces to form zinc sulfate. While contamination by chemical change could occur in any location its effect would be most prominent in industrial areas.

The investigation attempts to follow two approaches.

1. Carry out a fundamental testing program to better understand the behavior of different insulator types under contaminated conditions.

2. Develop a practical acceptance test for all types of insulation, line as well as station.

Under the fundamental testing program artificially contaminated insulators are compared with each other and insulators from polluted environments are compared with artificially contaminated units.

DESCRIPTION OF TEST METHOD 1

During fog room tests at Project UHV, four insulator strings were usually tested in parallel each time. Small fuses (1/2A) were put in series with each string to cut it off from the energized line upon flashover. Although these fuses could not clear the arc, their complete disintegration when flashover occurred allowed the dropping of the test lead and reclosing of the circuit breaker within a half minute after tripping. Test voltages involved were 230 kV and 125 kV for these exploratory tests. Fig. 1 shows the inside of the fog room. Steam fog was generated by electric heating elements placed in tubs of water to produce a slow wetting condition. The leakage resistance of contaminated insulators in the fog room changed slowly.

Voltage was applied to the insulator strings before the start of fog generation. The steam fog filled the room gradually in 1 to 1-1/2 hours, and the whole test lasted about 2-1/2 hours.

For the fog room tests, the insulators were dipped in a solution containing kaolin of fullers' earth and salt. They were then dried by a hot air heater, or in the sun. The average salt deposit density on each insulator was measured by washing the undersurface of the insulators in a known amount of water and measuring the resistivity of this solution. Insulators with environmental pollution were tested in the same manner as the artificially contaminated units.

TEST RESULTS

Insulators with leakage distances ranging from 12-1/2 inches to 21 inches and with unit spacings from 5-3/4 inches to 9-5/8 inches were used on these tests. The type of units are shown on Figure 2 and characteristics appear in Table 1.

Figure 3 shows the relationship between flashover and salt deposit density with a coating thickness of 40 grams of kaolin per liter applied uniformly over the insulator surface. All flashover values have been reduced to standard unit spacings $(kV \div 5.75)$.

It is interesting to note that performance is not necessarily related to leakage distance alone. Insulator type D with 21 inches of leakage distance as compared to insulator (A), a standard ten inch disc, with 11-1/2 inches of leakage distance shows lower flashover levels. The conventional fog type insulator, type (E), with 17 inches of leakage distance as expected has higher flashover values than type A. Insulator type G also with 21 inches of leakage distance shows the best overall performance. This would then indicate the geometry of the porcelain can also be a significant factor in the flashover performance.

Examining the slopes of the curves, insulator A shows a rather steep slope at lower densities. Thus for slight increases in contamination large incremental changes in flashover voltages can occur. Unexplained behavior between insulator strings in the same general location , some flashing over while others sustain operating voltage, could possibly be explained by this flashover characteristic. The relatively flat slope of type G insulator would make is superior regardless of the degree of contamination.

The data in Figure 3 can be made more useful by relating it to expected insulator usage. The user wants to know how many insulators are needed and if a certain type is used what is the connecting length?

Table 2 shows these values at certain expected operating voltages, for both light and heavy contamination. The fewest number of units, 16 for 500 kV, as well as the shortest connecting length, 112 inches, are shown by type G. This shorter connecting length could be an important element in tower design. The final selection of insulator string lengths will also depend on wet switching surge performance.

A need to correlate the previous data with insulators polluted under actual operating conditions was recognized as being extremely important for practical application reasons.

The measurement of contamination on insulators sent to UHV Pittsfield for evaluation and analysis are shown on Figure 4. Areas 1, 2,3 and 5 represent industrial contamination. Areas 1 and 2 represent extremely heavy contamination possibly of mechanical nature and having flashover behavior quite different from that of normal salt atmospheres as shown by area 4. Thus the usefulness of Table 2 is limited to salt atmospheres and industrial atmospheres similar to area 3. Before greater correlation between artificial contamination and industrial contamination can be realized much more investigation and testing needs to be completed.

DESCRIPTION OF TEST METHOD II

In IEEE Transaction Paper 69TP14-PWR "A New Contamination Test Method" a modified wet contamination test is described in great detail. A brief summary of this test method is as follows:

The insulators are flow-coated starting at the top and working to the bottom with a stream of liquid that coats the complete surface to the point of run-off. Previous to the flow-coating operation the insulators are prepared by washing in a neutral detergent, rinsing with tap water, and drying with compressed air. It has been found possible to design apparatus to flow-coat large structures and the resultant coating has been found to be quite reproducible. The quantity of the coating, however,

in milligrams per square centimeter is somewhat less on the underside than on the top. This is also true of the dipping method and is probably due to the tendency to drip from the vertical surfaces. Furthermore, the flow-coating process can be carried on in any laboratory test area, and the residue flushed down the drain after test.

In the proposed "wet contaminant" test method the testing starts while the insulators are still wet, three to five minutes after the end of the flow-coating process. Although the objective of this test method is to determine the highest withstand voltage, initially a flashover is obtained to establish the voltage range. Therefore the voltage is brought up at a rate of about 7.5 kV/s to the flashover level, and the voltage recorded. A second test is then made repeating the whole washing, contaminating, and testing procedure except that this time an attempt is made to hold a withstand voltage tne percent below the flashover value. The complete test is repeated several more times until three withstands and no flashovers are received at some voltage level. This is then called the withstand voltage for the particular contamination level applied and is usually determined within five percent.

The above describes the method when used for development work to obtain design data. When used for a standard acceptance test method, one or more tests at the required withstand voltage can be specified.

There are two factors involved in this method that contribute to reproducible results. First, it has been found that with a little care the flow-coating nozzles can be shaped so that all of the insulator surfaces are covered to the point of run-off. The coating efficiency can be readily inspected by examination when wet, before applying the voltage, and also after the insulators have dried. Second, the flashover strength is dependent upon the amount of water held on the surface as well as the amount of solid material deposited. In the case of the "wet contaminant" method all tests are made with the surface completely wet.

The apparatus used to accomplish the flow-coating can be readily constructed from copper tubing. In Figure 5 is shown the apparatus used to coat suspension insulators. In this figure the contaminating liquid is pumped under pressure to the continuous copper ring which surrounds the insulators. On the inside surface of the ring 16 short sections of copper tubing about 6 mm in diameter (1/4") protrude. Half of these have a slight curve upward and sidewards so that the liquid is directed up along the grooves on the underside of the insulators.

The degree of contamination on the insulator surface can be measured in several ways. First, the amount of salt and binder in the flow-coating liquid can be specified. Second, since the contamination coating is not altered by the test, all or part of an insulator coating may be washed off in distilled water, the conductivity measured, and the amount of salt in solution determined by comparison with standard curves. The equivalent salt deposit density can then be computed. Third, before applying high voltage to the test specimen a low voltage can be applied, and the leakage current measured. The conductance can then be computed, and finally the surface conductivity can be calculated by multiplying the conductance by the form factor for the surface being investigated.

The form factor is not generally available and must be calculated from measurements made on a drawing of the insulator cross section using the formula

$$f = \int_0^\ell \frac{d\ell}{\pi D(\ell)}$$

where ℓ denotes the total length of the leakage path and $D(\ell)$ the diameter of each element of the leakage path.

Although the results obtained using this method (Figure 6)* show lower withstand levels than those under test method 1 there is no inconsistency in results. This test method was not intended to reproduce any natural pollution conditions. The

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*(9 standard insulators and 8 fog type insulators per string used in these tests)

objective, to provide a relatively simple means for evaluating insulators is enhanced since minimum withstand levels will show safe margins below those that could be expected. The high degree of consistency as well as reproducibility as shown by Fig. 6 clearly demonstrates the value of this test method as an acceptance test. Also effective discrimination between designs as well as insulator types could permit writing specifications for contaminated applications.

CONCLUSIONS

1. When contamination by mechanical means, soluable salts, in the dominant factor in reducing flashover certain types of insulators show a marked superiority over others.

2. The criteria for good performance is not solely leakage distance. The geometry of the porcelain design can also effect flashover..

3. Expected operating performance can be predicted for different insulator types.

4. Artificial contamination cannot be reliably used to predict insulator performance under industrial contamination.

5. More investigation of industrially contaminated insulators is required.

6. A new type of contamination test method is being proposed that can be readily applied to all types of insulating structures and does not require highly specialized equipment or test facilities.

7. Although not attempting to reproduce any particular natural condition the wet contamination method can be used as an effective means in determining insulator specifications to be applied in any contaminated areas.

TABLE I

Type	Spacing	Diameter	Leakage Length	Mechanical Strength
A	5 3/4	10	11 1/2	30,000 lb.
B	6 1/4	11	14 1/2	50,000
C	7 3/4	12 5/8	16 3/4	66,000
D	9 5/8	15 3/4	21"	90,000
E	5 3/4	10 1/2	17	15,000
F	6 1/2	12 1/2	18 1/2	
G	7	12	21	40,000

TABLE 2

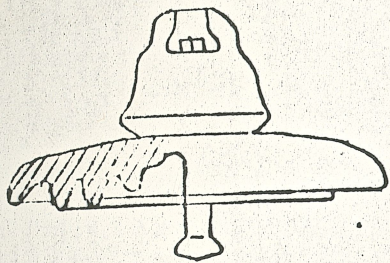| Type	0.05 mg/cm² 115 kV	230 kV	345 kV	500 kV	765 kV	0.1 mg/cm² 115 kV	230 kV	345 kV	500 kV	765 kV
A	6 (34.5)	11 (63.5)	17 (98)	25 (144)	38 (220)	7 (40.5)	13 (75)	20 (115)	30 (172)	46 (265)
B	5 (31.4)	9 (56.5)	14 (88)	20 (125)	31 (190)	6 (38.5)	11 (69)	16 (100)	23 (144)	35 (220)
C		10 (77)	15 (115)	21 (163)	32 (250)		11 (85)	17 (132)	24 (186)	37 (284)
D			12 (115)	17 (165)	26 (252)			13 (125)	18 (174)	28 (265)
E	5 (29)	10 (57.5)	15 (86.5)	22 (127)	34 (195)	6 (35)	11 (63.5)	17 (98)	25 (144)	38 (220)
F		8 (52)	13 (85)	18 (117)	28 (180)		9 (59)	14 (91)	20 (130)	31 (200)
G		7 (49)	11 (77)	16 (112)	25 (170)		8 (56)	12 (84)	18 (126)	28 (192)

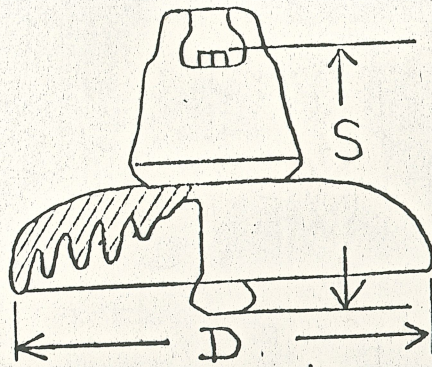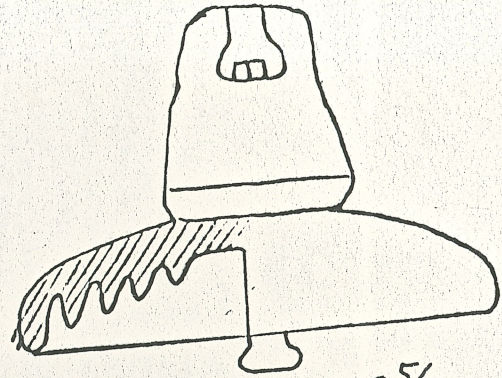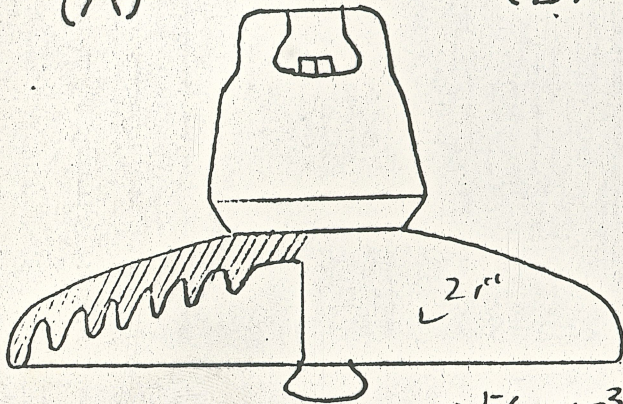SYSTEM VOLTAGE % 1.732 FOR LINE TO GROUND

Fig 2

$5\frac{3}{4} \times 10$

(A)

S

D

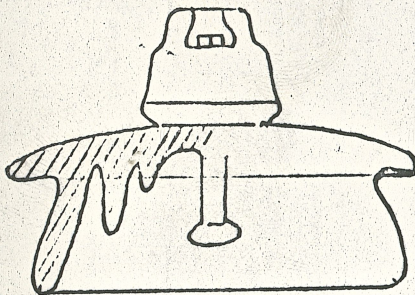(B) $6\frac{1}{4} \times 11$

$7\frac{3}{4} \times 12\frac{5}{8}$
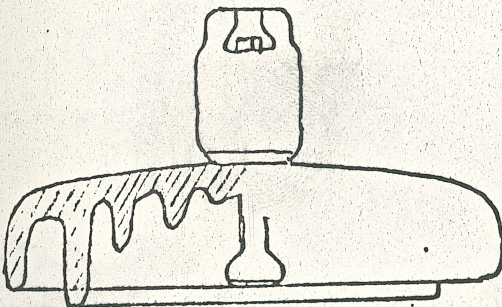
(C)

(D)

$2''$

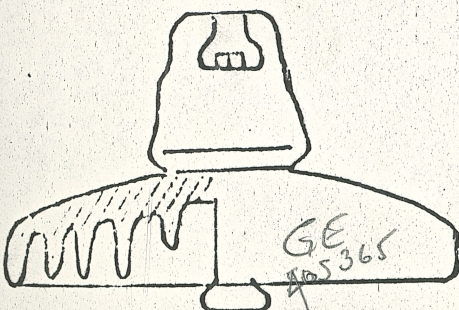$9\frac{5}{8} \times 15\frac{3}{4}$
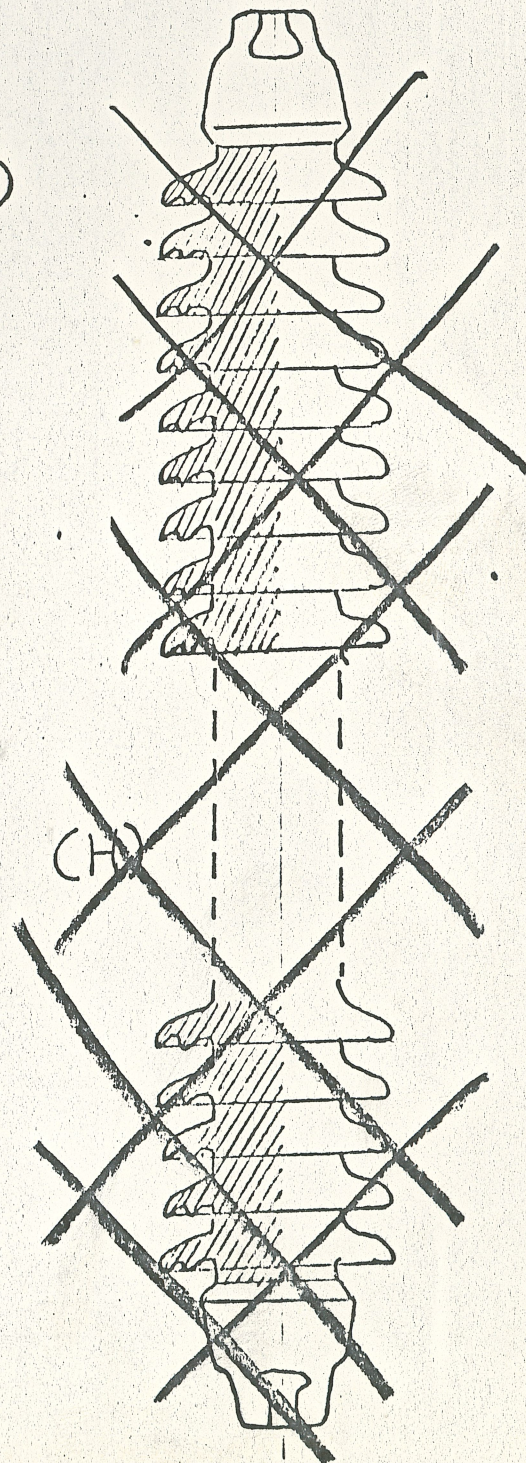
(E)

$5\frac{3}{4} \times 10\frac{1}{2}$

(F)

$6\frac{1}{2} \times 12\frac{1}{2}$

(G)

GE
A95365

7×12

(H)

FIG 2

Fig 3

CRITICAL FLASHOVER VOLTAGE Kv/unit (5¾ x 10 BASE) ← LINE TO GROUND

0 FLASHOVER

SALT DEPOSIT DENSITY   Mg/cm²

FIG 3

Fig.4

Graph: CRITICAL FLASHOVER VOLTAGE Kv/unit (y-axis, 6 to 24) versus SALT DEPOSIT DENSITY Mg/cm² (x-axis, 0.03 to 0.5). Curves labeled KAOLIN 40 g/ℓ and KAOLIN 80 g/ℓ. Areas marked AREA-1, AREA-2, AREA-3, AREA-4, AREA-5.

FIG 4

WITHSTAND VOLTAGE - kV

SURFACE CONDUCTIVITY - MICROSIEMENS

○ STANDARD INSULATORS
▷ FOG INSULATORS } FIRST TESTS

○ STANDARD INSULATORS
▷ FOG INSULATORS } REPEATED TESTS